

GEARTECH Report No. 2070-1
Guidelines for Wind Turbine Gearboxes

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GEARTECH

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INTRODUCTION

Obtaining reliable gearboxes for wind turbines is a difficult task. The parties involved, from wind turbine manufacturers to gear manufacturers, must be aware of the severity of the application. Wind turbines are subjected to widely varying loads, severe vibration, and a hostile environment. Extreme power may be many times rated power. To obtain a reliable wind turbine gearbox, it must be purchased with a specification that takes into account these factors and ensures a properly designed gearbox with good quality and workmanship. All phases of gearbox procurement including specification, design, manufacturing, testing, transport, commissioning, and operation must be carefully audited to ensure reliable service.

Requiring gearbox manufacturers to be registered to a quality standard such as ISO 9001 is not adequate to control gearbox quality. Our experience has repeatedly shown that ISO 9001 registration does not guarantee adequate quality or workmanship. ISO 9001 registration requires a company to have a system for documenting their manufacturing. However, it does not guarantee expertise in designing and manufacturing a quality product.

There are a number of industrial standards such as ANSI/AGMA 2001-C95, ISO 6336, and DIN 3990 that give methods for rating gear load capacity. They are adequate for their intended purpose, but not adequate to serve as the sole standard for specifying wind turbine gearboxes. Therefore, they must be supplemented with a comprehensive procurement specification that is specific to a particular wind turbine application.

The procurement specification should require conformance to AGMA/AWEA 6006-AXX (formerly AGMA/AWEA 921-A97 *Recommended Practices for Design and Specification of Gearboxes for Wind Turbine Generator Systems*). AGMA/AWEA 6006-AXX is currently in draft form and is being reviewed by the AGMA wind turbine committee. It should be published in 2003. See GEARTECH Report 2070 for more information.

AGMA/AWEA 6006 gives guidance for specifying, selecting, designing, manufacturing, procuring, operating, and maintaining wind turbine gearboxes. However, the guidelines do not specify how to meet the requirements.

This report is intended as a supplement to AGMA/AWEA 6006. It explains checklists and quality procedures that give auditors the methodology for obtaining gearboxes that meet the requirements of AGMA/AWEA 6006.

Ideally, auditors representing purchasers should be experienced in all aspects of gearbox procurement. However, inexperienced auditors can perform effective audits if they know what to look for and what questions to ask. By obtaining necessary documentation, auditors can consult with gear experts if they need

assistance in interpreting test results. The key lies with the checklists and quality procedures listed in this report.

CHECKLISTS

Checklists are questionnaires that auditors complete with yes or no answers. If a particular response is yes, no further action is necessary. However, if a response is no, some explanation should be entered in the comment column as to why the requirement is not satisfied. Thus, checklists highlight those items that require follow-up.

Checklists have a column labeled “R” that may be used for questions that cannot be answered adequately with a yes or no response. Interpretation of the “R” is left to the auditor’s discretion. In some cases, it may mean that more research is required before a particular question can be answered. In other cases, it can be used as a relative ranking to indicate how well a particular requirement is met.

QUALITY PROCEDURES

Quality procedures specify tests and inspections that are necessary for quality control. They may have some or all of the following clauses:

1. Scope
2. Referenced documents
3. Terminology
4. Significance and use
5. Apparatus
6. Test specimens
7. Procedure
8. Interpretation of results
9. Acceptance
10. Report

Gear manufacturers may have their own test methods that may not conform to the quality procedures. In such cases, it is necessary for the gear manufacturer and purchaser to negotiate test methodology to develop quality procedures that are acceptable to all parties. It is imperative that quality procedures be defined before any manufacturing commences. Otherwise, there may be disagreement on test results.

Table 1 is a catalog of the checklists and quality procedures. An example checklist and an example quality procedure follow Table 1.

Table 1- CATALOG OF CHECKLISTS AND QUALITY PROCEDURES AS OF 12/31/02				
Checklist		Quality Procedure		Description
CK1000	✓	QP1000	✓	Procurement process
CK2000	✓	QP2000	✓	Procurement specification
CK3000	✓	QP3000	✓	Bid solicitation and evaluation
CK4000	✓	QP4000	✓	Gearbox design audit
CK4100	✓	QP4100	✓	Gear design audit
CK4200	✓	QP4200	✓	Bearing design audit
CK4300	✓	QP4300	✓	Shaft design audit
CK4400	✓	QP4400	✓	Seal design audit
CK4500	✓	QP4500	✓	Lubrication system design audit
CK5000	✓	QP5000	✓	Quality assessment
CK6000	✓	QP6000	✓	Quality assurance plan
CK7000	✓	QP7000	✓	Manufacturing schedule
CK8000	✓	QP8000	✓	Manufacturing audit
CK8100	✓	QP8100	✓	Gear raw material for carburized gears
		QP8101	✓	Gear raw material for through hardened gears
CK8200		QP8200		Gear tooth cutting
CK8300	✓	QP8300	✓	Heat treatment of carburized gears
		QP8301	✓	Procedure for preparing representative test coupons
		QP8302		Inspection of surface hardness
		QP8303	✓	Inspection of case depth
		QP8304	✓	Inspection of core hardness
		QP8305		Inspection of case microstructure
		QP8306		Inspection for carbides
		QP8307		Inspection for decarburization
		QP8308	✓	Inspection for carbon content
		QP8309		Inspection for microcracks
		QP8310		Inspection for secondary transformation products
		QP8311		Inspection for intergranular oxidation
		QP8312		Inspection for retained austenite
		QP8313		Inspection for core microstructure
		QP8314		Procedure for post carburizing cold treatment
CK8400		QP8400		Gear tooth grinding
CK8500		QP8500		Gear tooth inspection
		QP8501		Inspection of basic geometry
		QP8502	✓	Inspection of gear tooth accuracy
		QP8503		Inspection of gear tooth root fillets
		QP8504		Inspection of records for grinding stock removal
		QP8505		Inspection of gear tooth surface roughness
CK8506	✓	QP8506	✓	Inspection by magnetic particle
CK8507	✓	QP8507	✓	Inspection of grind temper
		QP8508	✓	Inspection of gear tooth surface hardness
		QP8509		Inspection frequency
CK8600	✓	QP8600		Gearbox assembly
CK8700		QP8700	✓	Gear tooth contact patterns
		QP8701	✓	Inspection of gear tooth contact patterns with soft compound
		QP8702	✓	Inspection of gear tooth contact patterns with hard lacquer
		QP8703	✓	Inspection of gear tooth contact patterns in a roll stand

Checklist		Quality Procedure		Description
		QP8704	✓	Inspection of gear tooth contact patterns in a gear housing
CK8800	✓	QP8800		Gearbox tests
CK8900		QP8900		Gearbox installation
CK9000		QP9000		Gearbox startup
CK9100		QP9100		Gearbox monitoring
CK9101	✓	QP9101		Gear system audit
CK9200		QP9200		Removing gearboxes from service
CK9201		QP9201		Storing gearboxes
CK9202	✓	QP9202	✓	Preparation and transport of gearboxes
CK9300		QP9300		Gearbox disassembly
CK9301		QP9301		
CK9302		QP9302		
CK9303		QP9303		
CK9304		QP9304		
CK9305	✓	QP9305		Bearing inspection/removal
CK9400		QP9400		

Symbol ✓ indicates Checklist or Quality Procedure is complete.

GEARTECH	CHECKLIST			No. CK4000	SHEET 1 OF 1
				Rev. A	
Gearbox Design Audit				BY RLE	DATE 3/22/98
				CKD JRM	DATE 3/23/98
PROPOSAL DATA					
Question	Y	N	R	Comments	
Does the proposal include the following documents:					
Load spectrum?					
Outline dimension drawing?					
Assembly drawing?					
Assembly bill of material?					
Lubrication schematic?					
Lube system bill of material?					
Detail drawings of gears?					
Detail drawings of shafts?					
Detail drawing of housing?					
Does the proposal include the following bearing data:					
Manufacturer?					
Type?					
Catalog number?					
Retainer type?					
Retainer material?					
Internal clearance?					
GEAR CALCULATIONS					
Question	Y	N	R	Comments	
Does the proposal include the following gear calculations:					
Pitting resistance?					
Bending fatigue resistance?					
Scuffing resistance?					
Load capacity of shaft fits?					
BEARING CALCULATIONS					
Question	Y	N	R	Comments	
Does the proposal include the following bearing calculations:					
Shaft fits?					
Housing fits?					
Life rating calculations?					
SHAFT CALCULATIONS					
Question	Y	N	R	Comments	
Does the proposal include the following shaft calculations:					
Stresses?					
Deflections?					
Fatigue resistance of shaft/splines/keyways?					
Ultimate load capacity of shaft/splines/keyways?					
HOUSING CALCULATIONS					
Question	Y	N	R	Comments	
Does the proposal include the					

following housing calculations:				
Stresses?				
Deflections?				
Fatigue resistance?				
Ultimate load capacity?				

GEARTECH	QUALITY PROCEDURE	No. QP4000	SHEET 1 OF 3	
		Rev. A		
Gearbox Design Audit		BY RLE	DATE	8/24/99
		CKD JRM	DATE	9/5/99
1. Scope				
1.1 This procedure covers the steps involved in auditing gearbox design.				
2. Referenced Documents				
2.1 AGMA/AWEA 921-A97 Recommended Practices for Design and Specification of Gearboxes for Wind Turbine Generator Systems.				
2.2 ANSI/AGMA 2101-C95 Fundamental Rating Factors and Calculation Methods for Involute Spur and Helical Gear Teeth.				
2.3 ANSI/AGMA 6001-D97 Design and Selection of Components for Enclosed Gear Drives.				
2.4 ANSI/AGMA 6010-E88 Standard for Spur, Helical, Herringbone, and Bevel Enclosed Gears.				
2.5 ANSI/AGMA 6023-A88 Design Manual for Enclosed Epicyclic Gear Drives.				
2.6 ANSI/AFBMA Std 11-1990 Load Ratings and Fatigue Life for Roller Bearings.				
2.7 GEARTECH Specifications:				
CK1000 QP1000 Procurement process				
CK2000 QP2000 Procurement specification				
CK3000 QP3000 Bid solicitation and evaluation				
CK4000 QP4000 Gearbox design audit				
CK4100 QP4100 Gear design Audit				
CK4200 QP4200 Bearing design audit				
CK4300 QP4300 Shaft design audit				
CK4400 QP4400 Housing design audit				
CK4500 QP4500 Lubrication system audit				
3. Terminology				
3.1 Gearbox design audit- The process of determining if the proposed gearbox and all of its components meet the requirements of the Procurement Specification.				
4. Significance and Use				
4.1 Significance and Use- A complete gearbox design audit including but not limited to gear detail drawings, assembly drawings and layout drawings is necessary to ensure the design meets the requirements of the procurement specification and has adequate capacity for the application.				
5. Procedure				
5.1. Proposal data- The proposal shall include all data listed in CK4000.				
5.2 Gear Calculations- Gear calculations shall be performed per Section 4.3.1, of AGMA/AWEA 921-A97, Gear Life Rating, and QP4100.				
5.3 Gearbox thermal rating- Gearbox thermal rating shall be performed per Section 4.3.2, of AGMA/AWEA 921-A97, Gearbox Thermal Rating, and QP4100.				

GEARTECH		QUALITY PROCEDURE	No. QP4000	SHEET 2 OF 3	
			Rev. A		
Gearbox Design Audit			BY RLE	DATE	8/24/99
			CKD JRM	DATE	8/24/99
5.4	Bearing calculations- Bearing calculations shall be performed per Section 4.3.3, of AGMA/AWEA 921-A97, Bearing Life Calculations, and QP4200.				
5.5	Shaft Calculations- Shaft Calculations shall be performed per Section 4.3.4, of AGMA/AWEA 921-A97, Shaft Life Ratings, and QP4300.				
5.6	Housing calculations- Housing calculations shall be performed as per Section 4.3.5, of AGMA/AWEA 921-A97, Housing, and QP4400.				
5.7	Lubrication system- The lubrication system shall be audited for conformance to Section 4.8 of AGMA/AWEA 921-A97, Lubrication System, and QP4500.				
5.8	Maintainability- The gearbox and lubrication system shall be audited for conformance to Annex E of AGMA/AWEA 921-A97, Operation and Maintenance, and the procurement specification.				
6.	Interpretation of Results				
6.1	Specification conformance- The results of the gearbox design audit shall be compared to the requirements of the procurement specification for the following categories:				
	<ul style="list-style-type: none">• Design features• Load capacity• Lubrication system• Maintainability				
7.	Acceptance Criteria				
7.1	Design features- Gearbox design features shall meet the requirements of AGMA/AWEA 921-A97 and the Procurement Specification.				
7.2	Load capacity- Gearbox components shall have load capacities meeting the requirements of the following Quality Procedures:				
	QP4100	Gear design audit			
	QP4200	Bearing design audit			
	QP4300	Shaft design audit			
	QP4400	Housing design audit			
7.3	Lubrication System- The lubrication system shall meet the requirements of QP4500.				
7.4	Maintainability- Gearbox maintainability shall meet the requirements of AGMA/AWEA 921-A97 and the Procurement Specification.				
7.5	Gearbox design audit- The gearbox design shall meet the requirements of the Procurement Specification.				
8.	Report				
8.1	The report shall include the following:				
8.1.1	Summary of gear life ratings and thermal ratings,				

GEARTECH	QUALITY PROCEDURE	No. QP4000	SHEET 3 OF 3	
		Rev. A		
Gearbox Design Audit		BY RLE	DATE	8/24/99
		CKD JRM	DATE	9/5/99
8.1.2 Summary of bearing life ratings,				
8.1.3 Summary of shaft life ratings,				
8.1.4 Summary of housing calculations,				
8.1.5 Summary of lubrication system audit,				
8.1.6 Summary of maintainability audit, and				
8.1.7 Recommendations for revisions to engineering specifications required for conformance to the procurement specification.				